THE EFFECT OF FRP COMPOSITES ON STRENGTHENING AND RETROFITTING OF RC SHORT COLUMNS

G. Ghodrati Amiri 1, H. Hamidi Jamnani 2 and A. Emdadi 3

1 Professor, School of Civil Engineering, Iran University of Science & Technology
Institute of Higher Education in Amirkola, Babol, Iran, ghodrati@iust.ac.ir
2 PhD Student, School of Civil Engineering, Iran University of Science & Technology, Tehran, Iran,
h_hamidi@iust.ac.ir
3 M.Sc., Azad Islamic University, South Branch, Tehran, Iran, arash_emdadi@yahoo.com

ABSTRACT

Seismic studies and experimental researches have shown that one of the most common failure modes for RC structures subjected to cyclic loads is shear failure. One of the most effective methods to overcome this problem and to increase ductility and shear strength is the use of FRP for confinement of member. In the present study, weak column and retrofitted ones (passive & active) have been modeled using “Seismostruct” program and have been compared with experimental studies as well. The improvement in value of energy dissipation observed in passive retrofitted specimens was up to four times greater than evident specimens. Drift angle was increased up to 2.5 times. Furthermore, active retrofitted specimens have demonstrated more adequate performance than passive ones which were about 20% in most cases.

KEYWORDS

FRP composite, wrapped jackets, confinement, fiber analysis

INTRODUCTION

Short columns may be created unexpectedly in structures, sometimes non-structural components such as infill and sometimes low story height will result in forming short columns in concrete structures. Shear mode is one of the commonest failure modes for RC structures subjected to earthquakes. Recent studies have shown that short RC columns are vulnerable in brittle failure. So, a large number of studies have been carried out to find appropriate methods to increase the shear strength of such columns. These methods can change the brittle failure mode to a ductile one. Obviously, Shear capacity of short RC columns is a function of parameters like: (1) Compressive strength and confinement of concrete, (2) Area of longitudinal and transverse bars and (3) Cohesion between steel and concrete (Galal & Ghobarah (2004) and Rahaei & Zomorodian (2005)). A great number of experiments and researches have been done to retrofit RC columns using passive confinement, such as those by Galal et al, (2005), Saadatmanesh & Ehsani (1997) and Saatcioglu & Ozbakkaloglu (2004). However, a few studies have been done with the use of active confinement. Those of Saadatmanesh et al, (1994) and Miyagi et al, (2004) are the samples of these studies. In the present study, both passive and active confinements have been investigated.

METHODOLOGY

In this study, five short cantilever RC columns whose ratio of shear span to depth is 2.5, have been selected and then retrofitted in both passive and active states. To consider confinement effect in Seismostruct (a Finite Element program capable of predicting large displacement behavior of space frames under static or dynamic loading which takes into account both geometric nonlinearities and material inelasticity (Seismostruct (2005))), for evident specimens, the relationships presented by Mander et al, (1998) have been used. For passive retrofitted ones, the relationships introduced by Galal et al, (2004 & 2005) and for active retrofitted ones, those introduced by Miyagi et al, (2004) have been used to calculate confinement factor. The specimens have been subjected to a constant perpendicular and cyclic lateral load. After being analyzed, the results were evaluated and finally compared with those of experimental studies (Mahdizadeh and Moghadam (2005)).
**SPECIFICATIONS OF THE SPECIMENS**

The selected specimens have been considered rectangular, with dimensions of 250x250 mm$^2$ dimensions and a height of 620 mm. As shown in Figure 1, Φ4 bars were used for transverse reinforcement and 12Φ12 for the longitudinal reinforcement. The spacing of transverse reinforcement was considered to be 50 mm at the column-foundation connection, the beginning of the column, and 100 mm for the rest. In Figure 2, the subdivision of a typical reinforced concrete cross-section is depicted. By applying a sufficient number of fibers (200-400), the distribution of material nonlinearity across the section area could be accurately modeled. In this article, the number of fibers has been chosen to be 250. For the passive retrofitted specimens, Aramid & Carbon FRP have been used and wrapped up to the height of 30 mm of the columns. For the active ones, prestressed FRP fibers having 40 mm width and spacing of 70 mm have been utilized. The mechanical properties are shown in Table 1.

![Figure 1. Elevation and section of the specimen (mm)](image1)

![Figure 2. Fibers applied for reinforced concrete section (Seismostruct (2005))] (image2)

**Table 1. Mechanical properties of FRP composites**

<table>
<thead>
<tr>
<th>Fiber Types</th>
<th>Thickness (mm)</th>
<th>Tensile Strength (MPa)</th>
<th>Modulus of Elasticity (GPa)</th>
<th>Ultimate Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aramid</td>
<td>2900</td>
<td>2.50</td>
<td>120</td>
<td>0.440</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.165</td>
<td>3800</td>
<td>240</td>
<td>1.55</td>
</tr>
</tbody>
</table>

For the convenience of studying, the specimens have been named as shown in Table 2.

**Table 2. Description of naming adopted for the specimens**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>One layer CFRP</td>
<td>C</td>
<td>Evident Column</td>
</tr>
<tr>
<td>A1</td>
<td>One layer AFRP</td>
<td>PR</td>
<td>Passive Retrofit</td>
</tr>
<tr>
<td>SC</td>
<td>Prestressed CFRP fiber</td>
<td>AR</td>
<td>Active Retrofit</td>
</tr>
<tr>
<td>SA</td>
<td>Prestressed AFRP fiber</td>
<td>L1</td>
<td>Level 1 axial force (N=0.2 \times A_p \times f_c)</td>
</tr>
<tr>
<td>1/n</td>
<td>Prestressed strain</td>
<td>L2</td>
<td>Level 2 axial force (N=0.4 \times A_p \times f_c)</td>
</tr>
</tbody>
</table>

| (ratio of ultimate strain of FRP) |
LOADING

Two types of loads which were considered for analyses are:
(1) Constant perpendicular axial load; and
(2) Time history lateral load.

The analysis operation is based on time history static procedure and the aforementioned models have been subjected to these loads simultaneously. The constant perpendicular load is considered to be 225 KN which is the ratio of compressive strength of concrete column \(0.2 \times A_g \times f'c\). The time history lateral load is employed as “applied displacement”, where the corresponding values are the displacement of column and time. These values can be acquired by dividing lateral displacement of column \(\Delta\) by its height \(h\). The values are defined as “drift angle \(R\)”. As shown in Figure 3, three successive cycles with the values of 0.5, 1.0, 1.5, 2.0 … have been applied at each drift angle.

![Figure 3. Time history lateral load (cycle versus drift angle)](image)

ANALYSIS RESULTS AND DISCUSSIONS

Hysteresis curves of shear-drift angle

In Figures 4&5, the obtained hysteresis curves of retrofitted columns wrapped with Carbon (PR-C1-L1, PR-C2-L1 & PR-C3-L1), Aramid (PR-A1-L1) and Glass (PR-G1-L1) in the passive state and the evident specimen (C-L1) have been shown. Regarding the given curves, the high efficiency of application of wrapped FRP can be observed in increasing the ductility and shear strength of retrofitted specimens. The specimens retrofitted with Aramid have shown more adequate ductility than those with Carbon and Glass. Furthermore, the ones retrofitted with Aramid and Carbon have shown more shear strengths than those with Glass.

![Figure 4. The hysteresis curves of PR-A1-L1, PR-C1-L1, PR-G1-L1 and C-L1](image)
In Figures 6&7, the obtained hysteresis curves of active retrofitted columns wrapped with prestressed Aramid fibers (AR-C2-SA-1/2-L1 & AR-C3-SA-1/2-L1) and passive retrofitted ones (PR-C2-L1 & PR-C3-L1) have been shown. The prestressing values are considered as $\frac{1}{2} E_{frp}$ which equals to 12500µs. Regarding the hysteresis curves, it can be understood that prestressing of AFRP fibers results in more efficiency to increase ductility and shear strength than the passive retrofitted ones.

**Energy dissipation diagrams**

In Figures 8&9, the amount of energy dissipation of the studied specimens which has a direct relation to the ductility of a structure has been shown. Regarding Figure 8, the passive retrofitted specimen with Aramid has the capacity of 14 cycles though the one with Carbon and Glass has the capacity of 12 cycles. In Figure 9, the effect of increasing in the number of CFRP has been shown.
Dissipated Energy

Figure 8. Energy dissipation of the passive retrofitted specimens (1-layer), loaded in level 1 (225 KN)

Dissipated Energy

Figure 9. Energy dissipation of the passive retrofitted specimens (multi-layer of CFRP), loaded in level 1

Shear force envelope curve of the specimens

In Figure 10, the variation of the column shear force versus drift angle has been illustrated. The passive retrofitted specimens have shown better performance than the evident ones, so confinement with the use of FRP composites improves the sudden decrement of shear strength in the evident specimen.

Comparison of analytical hysteresis curve with the experimental studies

Due to the differences between material properties in theory and experiment and also probable errors in analysis, a comparison has been made between an analytical model and the concerned experimental one. As illustrated in Figure 11, there is a satisfactory conformity among analytical and experimental models.
CONCLUSIONS

According to the results of abovementioned analyses:
(1) Confinement with the use of FRP composites can greatly increase the ductility, energy dissipation and shear strength of the specimen.
(2) The shear failure mode of short RC column (which is a brittle mode) can be changed to a ductile mode using FRP composites.
(3) The amount of ductility derived by AFRP composites is more than the CFRP ones because of higher strain capacity, though the shear strength of CFRP is higher than that of AFRP type.
(4) Active retrofitted specimens have shown better performance than passive ones, up to 20% increment in shear strength and up to 40% in energy dissipation.
(5) The ratio of increment of energy dissipation for retrofitted specimens varies from 1.7 to 4 times as evident specimens.
(6) The rate of drift angle in retrofitted specimens increases up to 2.5 times.

REFERENCES

SeismoStruct, 2005. European School for Advanced Studies in Reduction of Seismic Risk (ROSE School), University of Pavia, Italy.